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by

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Design of a large angular aperture TeO_2 acousto-optic tunable filter

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Abstract

In this paper the design of a large angular aperture acousto-optic tunable filter (AOTF) using TeO_2 crystals is described. A new crystal orientation with $\theta_a=100°$ and $\theta_i=23.4°$ is proposed. It has been proven in the experiments that this AOTF meets the exact condition of tangent momentum match. The measured tuning relation is in good agreement with theoretical calculations and the spectral resolution has been improved by nearly 10Å. After compensation, the change in deflection angle is decreased to $\pm 0.06°$.

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Acousto-optic tunable filter (AOTF) is a new type of light separating device. It has the advantages of electronic tuning and has solved the problems in some fields that can not be solved by devices such as prisms or light grating. The characteristics of acousto-optic tunable filter are mainly determined by the relationship between the incident angles of acoustic and optic signals, θ_a and θ_i, and the requirement for the accuracy of these angles is always very strict. In previous designs, the following formula, given by Chang[1], was used to obtain the relationship between θa and θi.

$$tg\theta_i \; tg(\theta_a - \theta_i) = 2 \tag{1}$$

When $\theta_a=100°$, the optimum θ_i predicted by Chang was $20.7°$. However, we found that the accuracy implied in equation (1) is not sufficient when the highly accurate crystal orientation is encountered. The experimentally obtained tuning curves of the AOTF's based on equation (1) have larger deviations from the theoretical curves and the sensitivity of momentum match to the change in θ_i is significant. The purpose of this paper is to calculate the crystal orientation, based on accurate formula, which satisfies the tangential momentum match, and observe the effect of light incident angle θ_i on the momentum match and further test the major characteristic parameters of the acousto-optic tunable filter based on the new crystal orientation.

I. Theoretical Design

From the principle of the mutual acousto-optic interaction, it is known that,

$$k_i + k_a = k_d \tag{2}$$

where k_i, k_d and k_a are the wave vectors of incident light, diffracted light, and sound. Large angular aperture AOTF requires that when the angle of incident light deviates from its incident direction by a small amount, the diffraction characteristics will not be affected and momentum conservation will still hold. Therefore, when f_a and λ_0 are both constants, the derivative of (2) is,

$$\delta k_d = \delta k_{i0} \tag{3}$$

The physical interpretation of this equation is seen in figure 1. The tangent lines of the wave vectors at the tips of the incident light vectors k_i and diffracted light vector k_d are parallel, which means that the energy transmission directions of the incident and diffracted light vectors are the same. From figure 1,

$$k_i \sin\theta_i + k_a \sin\theta_a = k_d \sin\theta_d \tag{4}$$

$$k_i \cos\theta_i + k_a \cos\theta_a = k_d \cos\theta_d \tag{5}$$

where θ_i . θ_d and θ_a are the included angles between the incident light vector, deflected light vector, and sound vector and crystal orientation [001]. From (4) and (5), one can obtain $k_a = [k_i^2 + k_d^2 - 2\, k_i k_d \cos(\theta_d - \theta_i)]^{1/2}$. Therefore,

$$f_a = \frac{V}{\lambda_0}\left[n_i^2 + n_d^2 - 2 n_i n_d \cos(\theta_d - \theta_i)\right]^{\frac{1}{2}}, \tag{6}$$

where

$$\frac{1}{n_i^2} = \frac{\cos^2\theta_i}{n_e^2} + \frac{\sin^2\theta_i}{n_o^2}, \tag{7}$$

where n_o and n_e can be expressed in terms of Sellmeier formula[2]

$$n_o^2 = 1 + \frac{2.5844\lambda^2}{\lambda^2 - (0.1842)^2} + \frac{1.1557\lambda^2}{\lambda^2 - (0.2638)^2}, \tag{8}$$

$$n_e^2 = 1 + \frac{2.8525\lambda^2}{\lambda^2 - (0.1842)^2} + \frac{1.5141\lambda^2}{\lambda^2 - (0.2631)^2}. \tag{9}$$

Equation (6) is the accurate tuning relationship of the acousto-optic tunable filter. Theoretically, for the non-colinear acousto-optic tunable filter of the tangent wave mode of the abnormal Bragg diffraction type, the incident and diffracted light vectors are orthogonally interrelated. Hence, when the incident light is e light excited, the diffracted light is o light excited, and therefore, $n_d = n_o$

From the requirement of the parallel condition of the tangent lines in figure 1, we can obtain,

$$\mathrm{tg}\ \theta_d = (n_o/n_e)^2\ \mathrm{tg}\ \theta_{io} \tag{10}$$

from (4) and (5) we can obtain,

$$\mathrm{tg}\ \theta_a = (n_i \sin\theta_i - n_d \sin\theta_d)/(n_i \cos\theta_i - n_d \cos\theta_d) \tag{11}$$

and from the coupled equations of (7), (10), and (11), it can be solved that when $\theta_a = 100^o$, the corresponding light incident angle is $\theta_i = 23.4^o$. Of course, the conditions of other parameters can also be obtained from the above calculations.

II. EXPERIMENTAL RESULTS

In order to understand the sensitivity of the large angular aperture acousto-optic tunable filter to the changes in θ_i, and whether the tangential momentum match can be satisfied, a monochrome convergent light was directed to the tunable acousto-optic filter to observe the condition, when λ and f_a are constant, of the change in θ_i and use the diffracted light spot of the AOTF to detect the sensitivity of momentum match to the change in θ_i. Figure 2 shows the experimental setup. Figure 3 shows the diffraction spot of the AOTF when $\theta_a = 100^o$ and $\theta_i = 20.7^o$. Figure 4 shows that diffraction spot of the AOTF when the $\theta_a = 100^o$ and $\theta_i = 23.4^o$. The horizontal direction of the figures is the direction of the light incident angle θ_i, the light spots at the left of the figures are the light spot without diffraction and the light spots at the right of the figures are the light spots with diffraction. From the principle of acousto-optic interaction, the light that can be diffracted must satisfy momentum match condition. Therefore, from figure 3, we can see that only part of the incident light satisfies the momentum match condition and the effect of the change in θ_i on momentum match is significant. Since the diffracted spot in figure 4 is a lighted spot, which shows that for the AOTF of $\theta_a = 100^o$ and $\theta_i = 23.4^o$ the sensitivity of momentum match to the changes in θ_i is not significant and large angular aperture can be obtained.

The dashed curves in figures 5 and 6 are the tuning curves based on light grating spectroscopy and frequency measurement, the solid lines are obtained based on equations (6) and (10) and the symbols are experimentally measured data points. From figure 5, experimental data and theoretical prediction are consistent (the deviation is caused by sound scattering). The difference between experimental data and theoretical data is somewhat greater in figure 6. The reason lies in the fact that tangential momentum match between θ_i and θ_a is not satisfied for the AOTF based on these parameters. Naturally, the condition based on which equation (10) was derived is not satisfied and the difference between theoretical prediction and experimental measurement was rendered.

For the AOTF based on new crystal orientations, after increasing θ_i, sound excitation frequency was lowered a little bit and light spectrum distinction capability was enhanced. For the two devices with similar parameters but different light incident angles, the $\Delta\lambda$ at wavelength λ_0 of 6328Å can be increased by 10Å. For example, the AOTF with an original θ_i of 20.7°, the $\Delta\lambda$ measured at λ_0=6828Å, was 48Å. After changing θ_i to 23.4°, $\Delta\lambda$ for the same device was increased to 31Å. Furthermore, we have studied the effect of change of the diffracted angle with regard to the diffracted wavelength, the compensated amount was calculated. A compensated angle of 6°48' was ground on the diffracted surface. For the AOTF after compensation, the change in diffracted angle, in the range of visible light, decreased from more than 1° to less than ±0.06°.

III. CONCLUDING REMARKS

As stated above, the TeO_2 acousto-optic tunable filter, when the crystal orientation was that θ_a=100° and θ_i=23.4°, satisfies the condition of tangential momentum match. A large angular aperture can be obtained in this parametric device and its characteristics are superior to the device with θ_i=20.7°. If the modification of the energy exchanger can be improved, the light spectrum distinction capability can be further enhanced.

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[1] I. C. Chang: Appl. Phys. Lett., 1974, 25, No. 7 (1 Oct), 370.
[2] I. C. Chang: Proc. SPIE, 1978, 131,2.

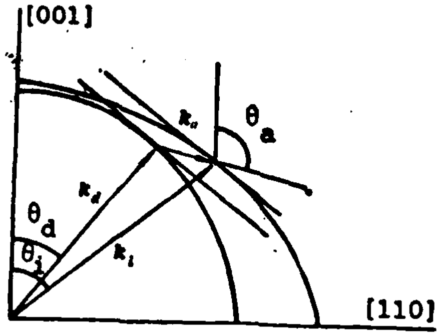

Fig. 1 Wave vectors representing acousto-optic interaction

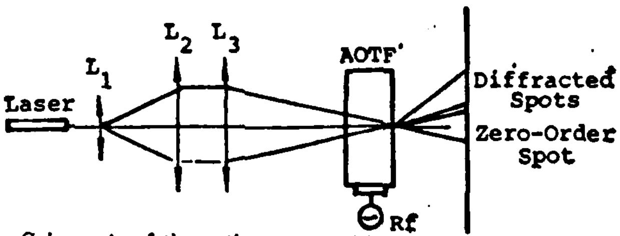

Fig. 2 Schematic of the optic system with an incident convergent light

Fig. 3 Diffraction of AOTF with $\theta_i = 20.7°$

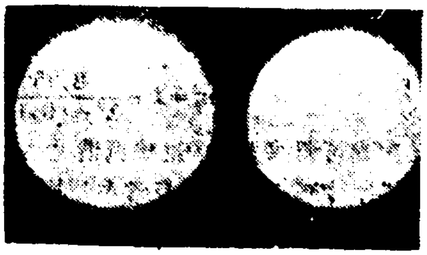

Fig. 4 Diffraction of AOTF with $\theta_i = 23.4°$

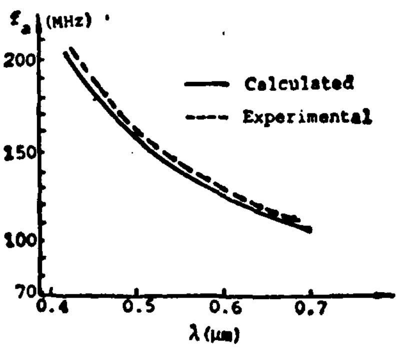

Fig. 5 Tuning curve for $\theta_i = 23.4°$

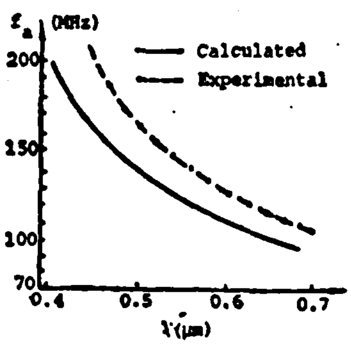

Fig. 6 Tuning curve for $\theta_i = 20.7°$

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